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A BRIEF ACCOUNT OF THE D. O. MILLS EXPEDITION TO CHILE.

By W. W. Campbell.

The D. O. Mills Astronomical Expedition from the Lick Observatory, University of California, will sail from San Francisco to-day* with destination in the neighborhood of Santiago, Chile. The work of the expedition will be largely technical, yet its purpose is to contribute to the solution of a perfectly definite problem.

It is well known that the observed positions and motions of celestial objects are influenced not only by the motions of the objects themselves, but also by motions of the observer. Not including several minor disturbances, the observer's motion is made up of three components:—

(1) That due to the rotation of the Earth on its axis. The elements of this diurnal motion are well known, and its effects can be eliminated completely from the observations.

(2) That due to the annual revolution of the Earth around the Sun. The form of the Earth's orbit is very well known, but there is at present an uncertainty of from one fourth to one half of one per cent in the size of the orbit. This introduces a slight uncertainty in the observer's speed, which is troublesome in a few cases. It is hoped that as a result of recent observations of the planet *Eros* we shall soon be able to eliminate the greater part of this uncertaintv.

(3) That due to the motion of the solar system (Sun, planets and their moons) through space. The elements of this motion are not well known. In fact, a general knowledge of them constitutes one of the most pressing problems in astronomy, and it is to contribute to the solution of this problem that the Mills Expedition to the southern hemisphere has been organized.

More than 100 years ago Sir William Herschel, from a consideration of the apparent motions of the few stars then accurately observed, came to the conclusion that the solar system is moving in a straight line approximately toward the constellation *Hercules*. This was in fact one of the shrewd guesses for which HERSCHEL is justly famous. Later solutions made by other astronomers, using the steadily increasing number of observed stars, have confirmed the approximate correctness of HERSCHEL'S result as to the point toward which the solar system is moving. They have, I think, without exception, located this point either in *Hercules* or in *Lyra*. Nevertheless, the various solutions leave an uncertainty of at least ten or fifteen degrees as to the direction of the motion.

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* February 28, 1903.

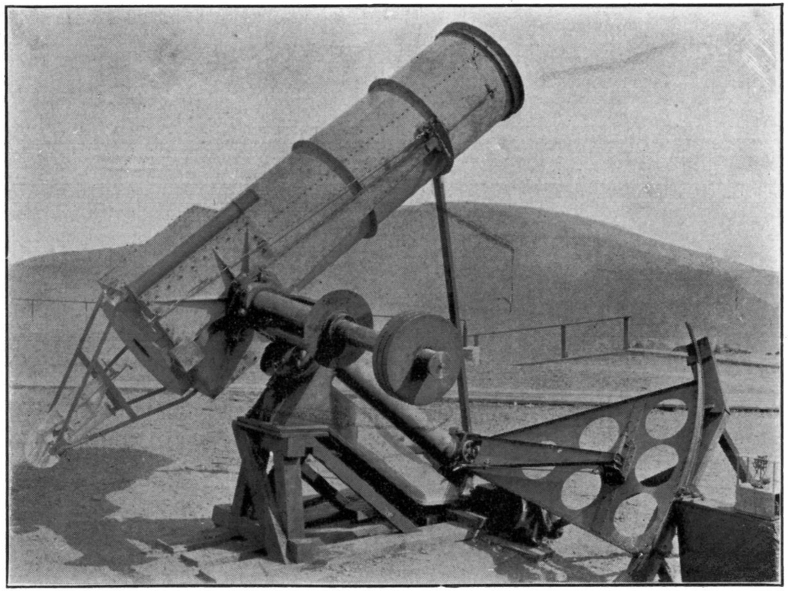
Our knowledge of the speed of the solar system has been much less satisfactory. HERSCHEL had almost no information as to the distances of the stars, but by making certain assumptions as to their distances he was led to the conclusion that the speed of the solar system is probably in the neighborhood of ten miles per second. Other discussions of the question have led to the assignment of values ranging from as low as five miles to as high as twenty-five miles per second. All these solutions were based upon the observed directions, and changes in the observed directions, of the stars, and involved assumptions as to the unknown stellar distances.

The development of the spectroscopic method of measuring stellar velocities in the line of sight of the observer has placed in our hands a means of making decided improvements in our knowledge of the solar motions, since this method is entirely independent of stellar distances. It is exceedingly simple in theory, but one of extraordinary difficulty in practice. It is based upon the fact, well known to students of physical science, that if a star is approaching the observer its spectrum will be shifted slightly as a whole toward the violet from its normal position, and if the star is traveling away from the observer its spectrum will be shifted slightly as a whole toward the red end.

These displacements of the spectra, due to the velocities of the stars, are on so minute a scale that the errors of observation may readily exceed the magnitude of the quantities to be observed. Fortunately the thorough understanding of the problem, reached through what have been bitter experiences to some observers, has made it possible at the present time to measure stellar velocities with a high degree of accuracy. The displacements of the spectra referred to, measured with the instruments now in use for that purpose, amount to only the thousandth part of an inch for a speed of fourteen miles per second. Yet we are able to measure spectrum plates very nearly to the one-hundredth part of a thousandth of an inch,—that is, nearly to the one one-hundred-thousandth of an inch. The evolution of instruments and methods and the precautions taken to enable us to reach this degree of refinement form an interesting part of the history of astronomy, but need not be considered here.

The velocities of some four hundred of the brighter stars have in the last seven years been measured with the D. O. Mills spectrograph attached to the great Lick telescope. These stars are distributed more or less uniformly over the three fourths of the sky visible from Mt. Hamilton. Two years ago I combined the results from these stars in an attempt to determine the elements of solar motion. It is evident that while the individual stars have individual motions, one moving in one direction, another in another direction, nearly all of them apparently independent of one another; yet if the solar system is moving toward a given point in the sky the stars in that portion of the sky will, on the average, appear to be approaching the solar system; and similarly, that the stars in the exactly opposite portion of the sky will appear to be moving away from the solar system. Conversely, if the velocities of the stars in all parts of the sky be known, it is possible by mathematical analysis to determine a point in the sky such that the stars within a concentric area will have the maximum velocity of approach to the solar system; and in the corresponding opposite area a maximum velocity of recession; the stars in other areas of the sky having systematically smaller speeds of approach or recession.

The solution referred to led to the result that the solar system is moving approximately in the direction of the southern boundary of the Lyre, with a speed of twelve and a half miles per second. There is no doubt that this result for speed is very close to the truth; but it is reasonably certain that the direction of the motion is somewhat in error. The weakness of the solution lies in the fact that the observed stars are not distributed uniformly over the entire sky. The region from thirty degrees south of the celestial equator to the south pole of the sky is not represented at all in the observational data.



THE D. O. MILLS REFLECTOR AND SPECTOGRAPH.

This deficiency affects the direction of motion vastly more than it does the speed. Before a satisfactory solution of this great problem can be made the stars in the one fourth of the sky around the south pole must be observed by methods similar to those employed at Mt. Hamilton.

It has for nine years past been my desire to organize at the proper time a spectroscopic expedition to the southern hemisphere for the purpose of securing these observations. Two years ago, the problems under solution and the needs of such an expedition were brought to the attention of Mr. D. O. MILLS, who promptly and most generously expressed the great pleasure it would afford him to provide funds for constructing the apparatus, for employing the astronomers, and for meeting the necessary expenses.

The telescope constructed for this purpose is shown in the accompanying illustration set up on Mt. Hamilton in the rear of the observatory for adjustment and trial. It is a reflecting telescope of Cassegrain form. I may remark that in a refracting telescope, such as the great Lick refractor, the rays of light from celestial objects pass through polished-glass lenses at the upper extremity of the telescope tube, and are brought to a focus at the lower extremity, where the eye of the observer is placed.

In this reflecting telescope, the upper end of the tube is open. The rays from a star pass down the tube to its lower extremity, where they fall on a silver-on-glass mirror, 37¼ inches in diameter. Its accurately polished surface, 36½ inches in diameter, has the curve of a parabola. The beam of parallel light from a star, upon striking the mirror, is reflected back, and an image of the star would be formed in the focus 17½ feet above the mirror; but a silver-on-glass hyperbolic convex mirror 10 inches in diameter, placed 4½ feet inside the focus, and just within the upper end of the tube, intercepts the rays. This small mirror is held in place by steel webs, which occult a small portion of the light from the star, but otherwise do no serious injury. This mirror turns the rays backward through a five-inch hole in the center of the large mirror, where they are brought to a focus a short distance below the telescope-tube, exactly on the slit of a powerful photographic spectroscope. The spectroscope is held in position by a steel truss. In theory it resembles the Mills spectroscope now in use at the Lick Observatory, but in reality it embodies many new departures based upon our seven years' experience with the older instrument. When in use the spectroscope will be completely inclosed in a temperature-case of aluminum, lined with hair felt and supplied with automatic electric heating apparatus, in order that it may be maintained throughout the night's observation at a constant temperature. The photographs upon which the results depend are of such exceeding delicacy that the small range of temperature which ordinarily occurs throughout the night would, if such precautions were not taken, render them almost valueless.

The mounting of the telescope was designed in general by the writer and in detail by the San Francisco firm of HARRON, RICKARD & McCONE. It was constructed in the shops of the Fulton Engine Works at Los Angeles. The optical parts of the telescope and spectroscope are from the well-known shops of the JOHN A. BRASHEAR COMPANY, Allegheny, Pa. The instruments will be covered by a modern thirty-foot steel dome, constructed by the WARNER & SWASEY COMPANY, builders of the great Lick telescope.

The dome and instruments will be mounted on the summit of one of the low hills near Santiago, where they will remain for two or three years. It is planned to measure the velocities of three or four hundred of the brighter stars in the southern sky. The photographs will be sent to the Lick Observatory for measurement and discussion. It is confidently expected that a combination of the spectroscopic results obtained at Mt. Hamilton and Santiago will lead to a very satisfactory solution of the troublesome problem of the motion of our solar system through space.

There is little doubt that, as in the Mt. Hamilton observations, the discoveries made as by-products of the investigations will rival in scientific interest the results which comprise the main purpose of the work. One or two of these by-products may be mentioned. It was found, for example, that at least one star in seven, and probably a very much larger proportion, is attended by invisible companions. This is in addition to the companion-stars visible in ordinary telescopes and known to astronomers as double stars. For instance, the North Pole star, which has perhaps been under observation more than any other for hundreds and thousands of years, was discovered, four years ago, to have two dark, invisible companions, making it a triple system; or, counting the distant, well-known visual companion, a quadruple system.

Great interest has been taken in the plans of the Mills Expedition by astronomers and others. A recent important committee, reporting upon plans for astronomical progress, gave recognition to the fact that the Mills Expedition from the Lick Observatory would be the first to undertake observations of this kind in the southern hemisphere, and expressed the opinion that it would be well if at least one more similar expedition could be dispatched to occupy this neglected field.

The importance of this line of work and the interest taken in it may perhaps best be expressed by referring to the fact that nearly all of the great refracting telescopes of the northern hemisphere have been engaged in it with greater or less degrees of success.

The Mills Expedition will be in charge of Acting Astronomer WILLIAM H. WRIGHT, who has ably assisted in the observations with the Mills spectrograph at the Lick Observatory in the last six years, and to whose valuable suggestions and help much of the success of the work is due. Mr. WRIGHT was graduated from the University of California in 1893. He will be accompanied by Assistant H. K. PALMER of the class of 1898, who was for four years on the Lick Observatory staff as fellow, and who is at present an instructor in the Berkeley Astronomical Department.

The Government of Chile has taken official notice of the coming of the expedition, and has generously offered to further its purposes in every way possible.

D. O. MILLS has taken a deep interest in the work of the Lick Observatory since his appointment thirty years ago as a member of Mr. LICK's first board of trustees, and he has contributed to its needs on four occasions in the past decade. I confidently expect that the results obtained by the expedition to Chile will be worthy of his splendid gift and of the observatory and university under whose auspices the work is undertaken.